within state health agencies, yet they also demonstrate changes in expenditures between fiscal years 1984 and 1989 that suggest declines in oral health programs within many agencies. Most noteworthy may be the increasing number of states that reported no categorical expenditures for oral health (for fiscal year 1989, 7 states [14%] of those responding to the Public Health Foundation survey). A 1991 survey of the Association of State and Territorial Dental Directors (unpublished data) suggests that, 2 years after the most recent Public Health Foundation data, the number may have been as high as 12 states and that an additional 13 states had lower oral health expenditures than 2 years earlier. Thus, in fiscal year 1991, nearly half of state health agencies were affected by dwindling oral health expenditures or a total lack of such expenditures. Given the great unmet dental needs documented for some US populations, it is disturbing that oral health expenditures represent less than 1% of all public health expenditures, particularly when it is known that, of all personal health care expenditures in the United States in 1990, approximately 5.8% involved dental services.[1]

The role of block grants in expenditures for oral health appears mixed. The total dollar amount of oral health block grant expenditures increased over time but decreased as a percentage of total oral health expenditures. This differential indicates that other sources of funding for oral health programs have increased, more so than block grants. The finding that 16 states reported no block grant expenditures for oral health in fiscal year 1989 may reflect either substantial support from state funds or marginal to nonexistent oral health programs in these states. □

Acknowledgment
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References
1. Oral Health Coordinating Committee, Public Health Service. Toward improving the oral health of Americans: an overview of oral health status, resources, and care delivery. *Public Health Rep.* 1993;108:657–672.
2. *Public Health Agencies 1991: An Inventory of Programs and Block Grant Expenditures.* Washington, DC: Public Health Foundation; January 1992:8–110.
3. *Public Health Agencies 1990: An Inventory of Programs and Block Grant Expenditures.* Washington, DC: Public Health Foundation; June 1991:8–109.
4. *Public Health Agencies 1988: An Inventory of Programs and Block Grant Expenditures.* Washington, DC: Public Health Foundation; July 1989:5–98.
5. *Public Health Agencies 1986: An Inventory of Programs and Block Grant Expenditures.* Washington, DC: Public Health Foundation; June 1987:3–93.
6. *Statistical Abstract of the United States 1990.* 110th ed. Washington, DC: US Bureau of the Census. 1989:xv.

The Effect of Passenger Load on Unstable Vehicles in Fatal, Untripped Rollover Crashes

R. A. Whitfield and Ian S. Jones

ABSTRACT

Consumers may be unaware of the risk of rollover crashes posed by passenger loads in vehicles with poor roll stability. This analysis demonstrates that certain sports utility vehicles and small pickup trucks have designs that are so unstable that the weight of the passengers in the vehicle affects its propensity to roll over. This effect occurs even though the weight of the loaded vehicle is less than the manufacturer's gross vehicle weight rating. The risk of a fatal, "untripped" rollover crash in vehicles with low roll stability is increased as each passenger is added to the vehicle load. (*Am J Public Health.* 1995;85:1268–1271)

Introduction

Estimates of the annual number of persons injured in motor vehicles that roll over typically exceed 50 000; the number killed exceeds 9000.[1] During the period of this study, 1991 through 1993, more than 2500 vehicles were involved in fatal, single-vehicle, "untripped" rollover crashes.[2] Yet different types of motor vehicles vary greatly in their involvement with rollover crashes. Those with high centers of gravity and narrow track widths have a marked tendency to overturn in certain types of turns or crash avoidance maneuvers. When measured per registered vehicle, average occupant death rates in small utility vehicles that roll over exceed the average in large passenger cars by a factor of 10.[3]

Despite these large differences in rollover risk, limited information is available to consumers about the relative stability of different makes and models of motor vehicles. The gross vehicle weight rating, however, is an important guide to safe vehicle operation that is universally accessible. This measure of a vehicle's loading capacity is found on the safety compliance certification label on the left front door of all vehicles sold in the United States. The rating is the manufacturer's estimate of the upper limit of carrying capacity for the safe operation of a particular vehicle. At a minimum, the gross vehicle weight rating must equal the weight of the empty vehicle plus an allowance for cargo plus 150 lb (68 kg) multiplied by the seating capacity.[4] In view of this rating, consumers may be unaware that filling the available passen-

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ger seats of certain utility vehicles and small pickup trucks can significantly affect the chances of a fatal crash from an untripped rollover. This loading effect is measurable far short of the gross vehicle weight rating for vehicles with poorly designed stability characteristics and suspensions.

The Dynamics of Vehicle Rollovers

Physical models of rollover crashes are divided into two categories: "tripped" (e.g., involving an impact with the vehicle's wheels or tires) and "untripped."[5,6] For a vehicle to overturn without tripping, the lateral acceleration in Gs must exceed the value of one half the track width of the vehicle divided by the center of gravity height of the vehicle.[5] That is,

$$a_y > \frac{y}{h}, \qquad (1)$$

where a_y is the lateral acceleration, y is one half the track width, and h is the center of gravity height. One G unit equals 32.19 feet/sec^2 or 981.27 cm/sec^2.

This expression does not take into account the weight of occupants or the load of the vehicle. Modifying Equation 1 to include the weight of the occupants, an untripped rollover occurs when

$$a_y\left(1 + \frac{m_{\mathrm{occ}}}{m_{\mathrm{veh}} + m_{\mathrm{occ}}} \times \frac{h'}{h}\right) > \frac{y}{h}, \qquad (2)$$

where m_{occ} is the occupants' mass, m_{veh} is the vehicle's mass, and h' is the occupants' center of gravity height above the vehicle's center of gravity height. In this paper, we refer to the term $m_{\mathrm{occ}}/(m_{\mathrm{veh}} + m_{\mathrm{occ}})$ as the occupant to loaded vehicle mass ratio.

Equation 2 shows that the lateral acceleration required for an untripped rollover is reduced as the occupant load increases in vehicles in which the passengers' center of gravity is above the vehicle's center of gravity. This suggests that the mass ratio should be related to untripped rollover propensity, an effect that has also been suggested experimentally.[7]

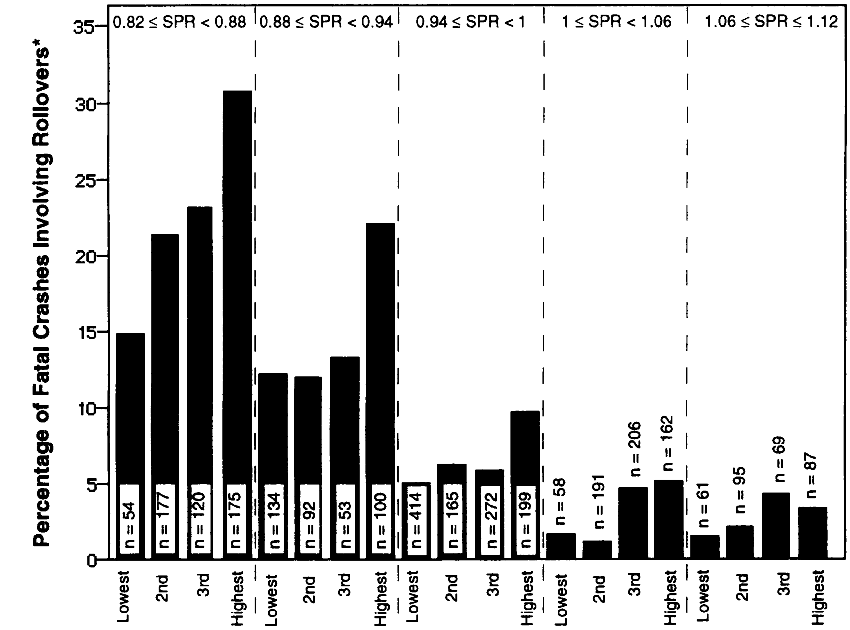
Methods

The National Highway Traffic Safety Administration's Fatal Accident Reporting System provides detailed information on motor vehicle traffic deaths in machine-readable form.[2] We used data from single-vehicle crashes not involving pedestrians that occurred over the period 1991 through 1993 to develop statistical models of untripped rollovers. In these models, we examined the roles of vehicle stability and passenger load in fatal, untripped rollover crashes, controlling for the effects of driver age, roadway speed limit, and dry pavement conditions.

First-event rollovers that occur on the roadway or shoulder indicate the occurrence of untripped rollovers (as recorded in the Fatal Accident Reporting System). "First event" means that the rollover is the first harmful event of the crash and that the rollover was not preceded by a collision with another vehicle or object. Our models compared single-vehicle, fatal crashes involving untripped rollovers with those that did not involve untripped rollovers. The differences between the two groups were used to construct models of the likelihood of rollover occurrence. We used multiple logistic regression techniques in constructing these models. JMP statistical software, produced by the SAS Institute, was used to estimate the equations in the derived models.[8]

Previous analyses[5,6,9-11] indicate that a number of different stability indices closely predict rollovers. We have chosen the side pull ratio to predict untripped rollovers, matching the side pull ratios of vehicles tested by the National Highway Traffic Safety Administration[9] to vehicles in the Fatal Accident Reporting System. The side pull ratio is determined by a test that measures the magnitude of the lateral force applied through the vehicle's center of gravity required to lift the opposite-side tires off the ground. This force is then divided by the vehicle weight to form the ratio. We prefer to use this metric because it is designed to be responsive to a suspension lift or "jacking" effect that takes place under dynamic conditions of lateral acceleration with certain types of suspensions. This causes the vehicle to be more prone to untripped rollovers (according to Equation 1). The side pull ratio is highly correlated with the static rollover stability factor used by many analysts. The correlation coefficient is .87 in our reference data set.

A total of 3839 vehicles transporting five or fewer occupants in single-vehicle, fatal crashes matched the National Highway Traffic Safety Administration's sample of tested vehicles with reported values for the side pull ratio. This matching was based on the vehicle identification number from the Fatal Accident Reporting System, as decoded by RL Polk & Co's PCVINA program[12] (to derive the vehicle make, model, series, model year, and number of driving wheels). (The National



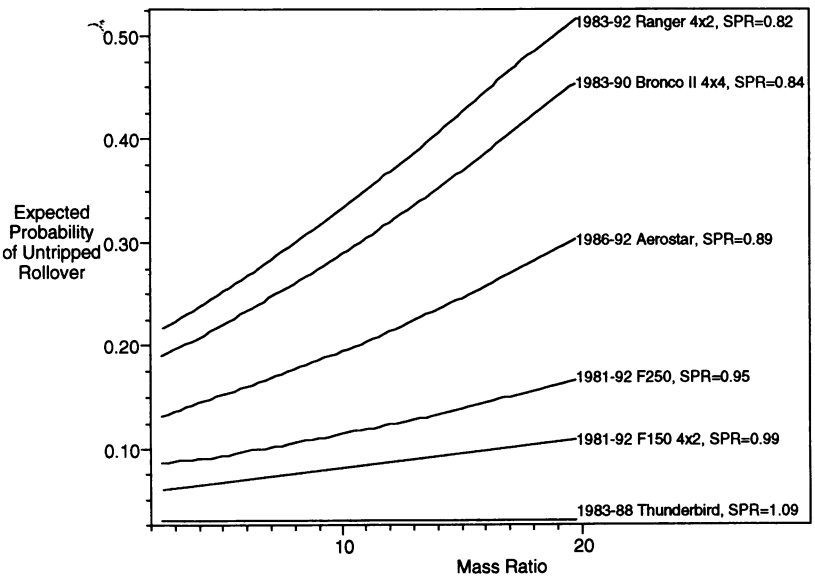
Note. SPR = side pull ratio.
*These rollovers are "first event" rollovers that occur on the roadway or shoulder.

FIGURE 1—Percentage of single-vehicle, fatal crashes (n = 2884) with an untripped rollover, by mass ratio quartile and stability index class.

TABLE 1—Logistic Model of Untripped Rollover Probability

Term	Estimate	SE	χ^2	P	df	−Log Likelihood
Intercept	−7.0746394	0.5705246	153.77	.0000		
Speed limit	0.05498415	0.0088035	39.01	.0000		
Inv(SPR)	7.81275913	1.1578769	45.53	.0000		
Mass ratio × Inv(SPR)[a] interaction	0.26289333	0.0855825	9.44	.0021		
Driver age	−0.0168817	0.0050005	11.40	.0007		
Dry pavement	0.74996274	0.2238321	11.23	.0008		
Model			251.2485	.000000	5	125.62427
Error					2786	763.85517
Total					2791	889.47944

Note. The number of observations was 2792. Rollover probability is expressed as the log of the odds ratio that (given a single vehicle, fatal crash) a first event rollover on the roadway or shoulder occurred as compared with the odds ratio that this rollover did not occur.
[a]The side pull ratio (SPR) has been reexpressed for ease of interpretation as Inv(SPR) = 1.12 − SPR. An increasing value of Inv(SPR) increases the probability of a rollover (1.12 is the value of the maximum original value for SPR in the data set).



Note. SPR = side pull ratio.

FIGURE 2—Comparison of predicted, untripped rollover probability, by mass ratio and design stability.

Highway Traffic Safety Administration reports a side pull ratio of 1.0 for the 1982 through 1992 GMC T-1500 pickup truck. However, because PCVINA does not identify this specific vehicle, we assigned this side pull ratio value to a "sister vehicle," the Chevrolet S-10 4 × 4 pickup truck.) Sister models equivalent to the National Highway Traffic Safety Administration tested vehicle were also matched. We eliminated from our analysis 700 vehicles without complete information about vehicle mass (obtained from PCVINA), 34 vehicles without complete information about rollover occurrence, and 31 vehicles without information for each occupant's age and sex (from the Fatal Accident Reporting System). We also eliminated 166 vehicles whose occupants shared seats or were not seated inside the vehicle in a standard seating pattern. In addition, 24 vehicles noted to be overloaded by the investigating officer were dropped from the analysis. The final sample size was 2884. In 92 of these cases, data were missing for the roadway speed limit, the driver's age, or the pavement condition at the crash site.

In our sample, vehicle occupants were assumed to be of average height for their age and sex. As a means of estimating the total occupant mass in each vehicle, the occupants were matched on the basis of age and sex with a table of average weights.[13] A comparison with the gross vehicle weight yielded the mass ratio used as an independent variable in the estimated statistical models defined below. The mass ratio is estimated as

$$\frac{\hat{m}_{occ} \times 100}{m_{veh} + \hat{m}_{occ}}, \qquad (3)$$

where $\hat{m}_{occ}$ is the estimated occupants' mass and m_{veh} is the vehicle's empty mass.

Results

Two hundred seventy-nine crashes in our sample involved an untripped rollover (about 10%). However, the propensity toward untripped rollover varied greatly among different makes and models of motor vehicles. Figure 1 shows the general relationship between vehicle stability, the mass ratio, and the percentage of single-vehicle fatal crashes involving an untripped rollover. The x-axis of the graph divides the side pull ratio into five categories and the mass ratio into four equal quartiles (lowest to highest). This allows a graphic comparison of the general effect of increasing stability and the effect of the mass ratio within each category of side pull ratio on the probability of rollovers in fatal crashes.

The graphic analysis suggests a pronounced effect of stability on rollover propensity. As vehicle stability increases through each stability category, the relative occurrence of rollovers decreases. Figure 1 also suggests that there is an interaction between stability and occupant mass that affects the likelihood of rollovers. At the lowest stability categories, the effect of the occupants' mass is most obvious. As stability increases, the effect dampens out.

We tested the formal hypothesis that an interaction effect between vehicle stability (measured by the side pull ratio) and mass ratio affects rollover propensity in a logistic regression model that controls for speed, driver age, and pavement condition. The estimated model is shown in Table 1.

The interaction effect of vehicle stability and mass ratio is illustrated in Figure 2. This figure shows the predicted probability of an untripped rollover as the mass ratio increases in six Ford Motor Co vehicles with differing design stability. The probability curves for each vehicle are derived by means of the estimated equation in Table 1. The figure is specific to vehicles with 31-year-old drivers (the median age in the sample population) on a 55 mile per hour (88 km per hour) roadway under dry pavement conditions. It can be seen from the figure that rollover propensity becomes highly dependent on the mass ratio as the design stability decreases.

Discussion

The physical models given in Equations 1 and 2 show that the interaction between the mass ratio and vehicle stability comes partly from the narrow track width of vehicles with low design stability. An additional element of the interaction comes from the passengers' seating in the vehicle above the empty vehicle's center of gravity. This circumstance particularly applies to sports utility vehicles and small pickup trucks. Because these types of vehicles tend to have low side pull ratio measures, the interaction is consistent with the physical models. In contrast, the seating of occupants in passenger cars tends to be closer to the plane of the vehicle's center of gravity. Passenger cars also tend to have high side pull ratio measures. These factors result in the lowering of the mass ratio/stability interaction effect as stability improves.

Conclusion

Since the early 1970s, the National Highway Traffic Safety Administration has investigated the need to issue regulatory standards governing the stability of motor vehicles; however, it has not, to date, issued such standards.[14] Without a stability standard, consumers must rely on the gross vehicle weight rating for information about the capacity of a particular vehicle to carry a load of cargo and passengers safely. Our data indicate that this rating is a misleading indicator of safe loading capacity for many sport utility vehicles and small pickup trucks with low design stability. In fact, these vehicles cannot carry the number of occupants for which there are seats without affecting their likelihood to overturn. Cargo loads in excess of the seating capacity further increase the rollover propensity. Our physical model of untripped rollovers also points to the danger of using the overhead luggage racks sold with many models or installed by consumers, because their location over the vehicle's center of gravity is far higher than that of seated passengers.

Auto manufacturers should account for the effect of passenger load on untripped rollover propensity in setting the gross vehicle weight rating for vehicles with poor roll stability. Until the manufacturers act, consumers should be aware that the gross vehicle weight rating is not a reliable guide to safe operation of unstable vehicles. Occupants in vehicles with low roll stability increase their risk of an untripped, rollover crash as each additional passenger is added to the vehicle load. □

References

1. *Notice of Proposed Rulemaking, Docket 91-68, Notice 03.* Washington, DC: National Highway Traffic Safety Administration; 1994.
2. *Fatal Accident Report System.* Washington, DC: National Highway Traffic Safety Administration; 1993.
3. *Status Report 27.* Arlington, Va: Insurance Institute for Highway Safety; 1992.
4. 49 CFR, Part 567.
5. Jones IS. *The Effects of Vehicle Characteristics on Road Accidents.* Oxford, England: Pergamon Press; 1976.
6. Jones IS, Penny MB. *Engineering Parameters Related to Rollover Frequency.* Detroit, Mich: Society of Automotive Engineers; 1990. Technical Paper 90-0104.
7. Garrott R. *The Variation of Static Rollover Metrics with Vehicle Loading and between Similar Vehicles.* Detroit, Mich: Society of Automotive Engineers; 1992. Technical Paper 920583.
8. *JMP Statistical Software, Version 3.0.2.* Cary, NC: SAS Institute Inc; 1994.
9. *Technical Assessment Paper: Relationship between Rollover and Vehicle Factors, Docket 91-68.* Washington, DC: National Highway Traffic Safety Administration; 1991.
10. Klein TM. Statistical analysis of vehicle rollover propensity and vehicle stability. *Auto Traffic Safety.* 1994; Winter:2–10.
11. Robertson LS. Risk of fatal rollover in utility vehicles relative to static stability. *Am J Public Health.* 1989;79:300–303.
12. *PCVINA.* Cincinnati, Ohio: RL Polk & Co; 1991.
13. *The World Almanac and Book of Facts.* New York, NY: Pharos Books; 1993:956.
14. *Planning Document for Rollover Prevention and Injury Mitigation, Docket 91-68, No. 1.* Washington, DC: National Highway Traffic Safety Administration; 1992.

Call for Abstracts for the Dermatoepidemiology Interest Group's 1996 Scientific Meeting

The Dermatoepidemiology Interest Group is inviting papers to be presented at a scientific meeting to be held February 9, 1996, in Washington, DC. This meeting will be an international forum for the presentation and discussion of ongoing investigation in epidemiology and health services research in skin diseases.

Abstracts will be selected by peer review, based on scientific merit. Desired topics include epidemiology of cutaneous disorders (including descriptive, analytic, interventional, and methodologic investigations) and health services research (including studies of dermatologic outcomes and the quality, costs, and delivery of care).

The deadline for submission is *October 2, 1995.* For more information or to obtain an abstract form, please contact Mary-Margaret Chren, MD, University Hospitals of Cleveland, 2074 Abington Rd, Cleveland, OH 44106; tel (216) 844-3177; fax (216) 844-8993.